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Frequency Assessment for Radio Astronomy in the Hydrogen Line: Statistical Investigation at *Pusat Astronomi Borneo*, Malaysia.

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Abstract: *This quantitative study assessed Radio Frequency Interference (RFI) in Pusat Astronomi Borneo (PAB) observation sites in Sarawak (1.3-1.5 GHz) focusing on the hydrogen line frequency (1420.4057 MHz). The RFI measurements were taken with a portable spectrum analyser, while mean, standard deviation, skewness and kurtosis values were applied in the descriptive analytics framework to quantify variations in the spectra. A threshold of -80 dBm based on ITU-R RA.769 was used to mark interference zones. Results indicate that Tengah_PDG displayed the best spectral conditions with the lowest average RFI (-81.23 dBm), lowest fluctuation (1.32 dB), scarce occurrence of interference hotspots and further complemented by robust terrain shielding. Other sites, like Bulatan_Off, exhibited stable characteristics, while Parit_Kuala showed bursty RFI with a high kurtosis value (2.12). The Kuala_Sg and Hut_Bulatan sites showed lower sheltering and greater exceedance in the thresholds. Findings support Tengah_PDG as the target observatory site for L-band radio astronomy while regionally advancing the sustainable management of radio frequencies and construction of quiet zones.*

Keywords: Astronomy Observation, Site-Testing, Radio Astronomy, Radio Frequency Interference, Hydrogen Line.

1. INTRODUCTION

Active engagement with reality allows us to scientifically study the universe, as detection of naturally occurring radio waves emitted from sources in the universe is now possible. This started in 1932 when Karl Julius Jansky, while working on static noise for Bell Telephone Laboratories, discovered radio emissions [1, 2]. His accidental find, and the pioneering sky surveys of Reber, gave rise to a whole new field of astronomy that can uncover new phenomena previously imperceptible to telescopic scrutiny. One of the most critical frequency ranges for radio astronomy is the L-band (1300 - 1500 MHz), particularly the 21-centimeter neutral hydrogen (H I) line at 1420.4057 MHz, which is essential for tracing the galaxy's structure, star formations and distribution of dark matter [3, 4]. The surging demand for telecommunication, aeronautical navigation, mobile telephony, and satellite communication gives rise to problems for passive services, such as radio astronomy. RFI in various regions of the Earth's surface is becoming increasingly more harmful to L-band observations, and it can distort or mask weak cosmic signals. The International Telecommunication Union (ITU) has established that frequencies ranging from 1400 to 1427 MHz are a protected passive band, excluding the possibility of usage for remote sensing under ITU RA.769 based on the reason that it is unengaged space. However, actual enforcement protecting it as sovereign law is left to each nation's commitment. The absence of formally defined Radio Quiet Zones, or a national policy framework that allows for controlled band protection, tends to limit opportunities, even with the existence of multiple observatory sites in Malaysia. Abidin et al. (2013) argued for stronger L-band protection on a subdivision of four sub-windows (A: 1400–1427 MHz, B: 1380–1400 MHz, C: 1350–1380 MHz, D: 1300–1350 MHz) but still no comparison studies on remote regional sites or modern long-term RFI suitability assessments have been carried out [5-7]. Concurrently, Roslan Umar et al. (2015) advocated the application of GIS when screening interference environmental data for low sites [8, 9]. These ideas form the present study's basis for its methodology and demonstrate the need for a comprehensive geographical and statistical approach for observatory site selection [10-11]. The problem regarding rationale for the selection requires a review of the RFI evaluation for planned observatories in Sarawak, especially its RFI protection criteria in, while solving the longstanding problem of finding a site for hydrogen line studies. These circumstances help the peripheral development in tourism to dictate which areas need defined borders for quiet interference levels for future investment in infrastructure that sustains radioastronomy. Radio waves are crucial for advanced astrophysical studies as they enable scientists to observe pulsars, fast radio bursts, black holes, and other cosmic phenomena. They enhance observation at different frequencies across the electromagnetic spectrum and provide valuable information on high energy and non-thermal processes. International collaboration to protect the radio spectrum for scientific purposes is evidenced by the construction of major facilities, such as VLA, LOFAR, MWA, GMRT, SKA and FAST in China [12]. These observatories work within the frequency range of 10 MHz to 25 GHz, with some studying the hydrogen line, solar activity, or transient phenomena. The situation is aggravated by rising radio frequency interference (RFI) from satellites as well as telecommunication and metropolitan electronics, which is especially problematic for lower frequencies [13]. Malaysia also faces this challenge caused by urbanized areas and uncontrolled satellite emissions. Scientists need to work with MYSA as well as government bodies to mitigate these issues by declaring these areas as Radio Quiet Zones (RQZ) and adopting global restrictions on the radio spectrum as well as requiring RFI profiling to ensure long-term sustainability of radio astronomical observations [14].

Concerning this, a recent site selection for RFI capabilities and comparative evaluation at the Pusat Astronomi Borneo (PAB) in Santubong, Sarawak, yielded encouraging findings [15]. Given the site's unique geographical isolation, the surrounding population as well as several cellular infrastructures, it was found to be suitable for radio-quiet operations. The assessments conducted with L-Band spectrum analysers indicated that the RFI levels throughout the HI Line ranged from 1400 to 1427 MHz. The –80 dBm was chosen as the threshold, considering the sensitivity level for most radio astronomy applications based on the astronomical signal frequency in fluctuations of interference mentioned in ITU-R RA.769-2. As for precise measurements, especially when detecting weak emissions from neutral rest hydrogen and other spectral lines, these signals must be lower than this threshold to preserve the scientific merit of the measurements. This present study's initial assessment applied kurtosis-based spectrum analysis and skewness statistics to investigate the spectral allocation of L-band at PAB [16]. The study introduced a systematic approach involving a combination of descriptive statistics and an *in situ* spectra analyser for assessing the site suitability for radio astronomy. These results strongly support the formal designation of PAB as an RQZ, adding substantial value for national planners in spectrum management and stakeholders in astronomy [17]. Furthermore, this study contributes to global initiatives on the sustainable management of frequency allocation and enhances Malaysia's research in developing radio astronomy in Asia. As astronomical observations become more dependent on observation sites with minimal interference and protected segments of the electromagnetic spectrum, specifically pertaining to radio astronomy, there is an urgent requirement for observation sites in Southeast Asia due to development concerns. This study's motivation to focus on Pusat Astronomi Borneo (PAB) in Santubong, Sarawak, merges with the growing need for dual-use optical and radio astronomical facilities. Its geographic remoteness, coupled with sparse urban development and limited telecommunication infrastructure, provides a robust justification for declaring a nationwide Radio Quiet Zone (RQZ) or Radio Notification Zone (RNZ).

This study addressed the strategic problem of assessing PAB's radio frequency landscape in the L-band (1–2 GHz) range and its suitability for radio astronomical observations, focusing on neutral hydrogen (HI) surveys. It seeks to provide empirical evidence to the national and regional spectrum management communities. It is anticipated that the results will aid the Radio Astronomy Frequency Committee of Malaysia (RAFCAM) in their decision-making processes and shape collaborative strategies within the framework of the Radio Astronomy Frequency Committee of Asia-Pacific (RAFCAP) [18]. Hence, this study aimed to enhance Malaysia's ability to actively engage in international radio astronomy endeavours and advocate sustainable frequency allocation planning for future observatories in the region.

2. METHODOLOGY

A comprehensive observational and analytical approach was adopted to determine the boundaries and severity of Radio Frequency Interference (RFI) in the L-band (1300–1500 MHz) based on the context of Malaysian observatory sites. This methodology combines field spectrum measurements, frequency analysis and statistical grading relative to the designated 1420.4057 MHz hydrogen line to determine the suitability of each site for radio astronomy [5]. Every step undertaken by this study is geared according to international standards for radio spectrum monitoring and site classification that is aimed at finding a suitable candidate for RQZ at Pusat Astronomy Borneo.

2.1 Site Selection

To spatially identify and analyse radio frequency interference (RFI) in the L-band, five sites were chosen within the compound of Pusat Astronomi Borneo (PAB). These sites were selected based on a certain combination of topographic diversity, land cover characteristics, and potential sources of anthropogenic RFI [18]. The selection reflects a purposeful stratified sampling of open elevated land as well as densely vegetated and obstructed areas.

Table 1. Coordinates and Surrounding Factors Related to Selected Observation Sites at Pusat Astronomi Borneo (PAB)

Bil	Location	Latitude (°)	Longitude (°)	Surrounding Factor
1	Kuala_Sg	1.7391	110.3154	Blocked by the hill and near the roadway
2	Hut_Bulatan	1.739	110.3113	Blocked by the hill, trees, and residential area
3	Bulatan_Off	1.7411	110.3069	Open site, high land, and residential area.
4	Parit_Kuala	1.7379	110.3031	Completely surrounded by the hill and trees.
5	Tengah_PDG	1.7459	110.3074	Jungle area.

These five sites were captured using GPS units with an accuracy of ±3m suffix, while local surrounding conditions were documented with field notes and photographs. Differences in environmental and human-made features, together with the selected points, provide an extensive assessment of the influence imparted by the local geography, vegetation and the RFI's infrastructure. In addition, the sites established a statistical model that could help in further analysis through *in situ* observation in the later stages with the aim of determining suitable radio astronomy regions within the proposed boundaries of the Radio Quiet Zone at PAB.

2.2 Measurement Configuration and Spectral Classification

This current study used a Protek 3290N portable spectrum analyser linked to a patch antenna with an estimated 5 dBi gain for performing measurements. The antenna was facing straight up to the zenith for maximize signal receiving, whereas the spectrum analyser was set to sweep the entire range of 1300 – 1500 MHz, with a bandwidth resolution of 1MHz. This enabled the detection of narrow band signals. Power levels were measured and recorded in decibel-milliwatts(dBm) at five observation points by using the analyser and any signal detected above -80 dBm was considered RFI. This threshold based on a conservative approach was derived from ITU-R RA.769-2 [4], which offers criteria designed to prevent and protect interference against radio astronomy activities.

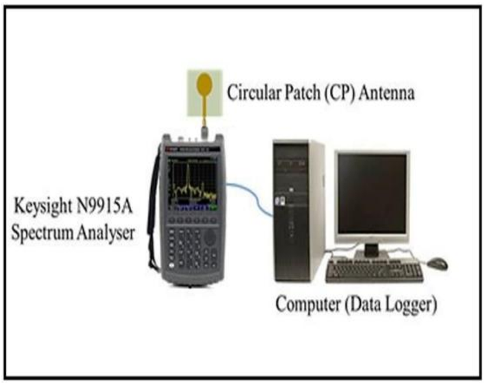

Fig. 1. Measurement Setup using Circular Patch Antenna, Spectrum Analyser, and Data Logging System

Although ITU standards mostly cite –60 to –70 dBm cutoff levels with respect to the observational mode, this study's use of –80 dBm enabled the detection of marginal low-level interference that would compromise more sensitive spectral-line and continuum measurements. The L-band spectrum was divided into four sub-bands based on a modification of Abidin et al. (2021) classification for better clarity. In Window A (1400–1427 MHz), hydrogen emission was observed from deep space and thus, it was a globally protected passive band reserved for HI observations. Window B (1380–1400 MHz) contained redshifted HI signals but may be partially overlapped by adjacent services. Window C (1350–1380 MHz) was moderately contaminated by satellite navigation and civil aviation systems, while Window D (1300–1350 MHz) was heavily contaminated by LTE downlinks, radar, and other terrestrial sources. Signal detections in these windows were classified to assess the presence and strength of interfering signals in scientifically important parts of the L-band [5]. Such framing helps improve understanding of the spectral environment at PAB, aids in characterizing the local radio frequency environment as well as helps plan and develop radio astronomy instruments and observational strategies to be deployed at the site in the future.

2.3 Statistical Methods and Equations

To assess the RFI spectral environment at each observation site in PAB, a statistical approach that included several features was adopted to assess spectral power distributions within the L-band (1300 to 1500 MHz). The first step was to compute mean power level (μ), which served as the average interference power, for the sweeping spectral range, which is given by:

$$\mu = \frac{1}{n}\sum_{i=1}^{n} xi$$

where x*i* is the power level in dBm corresponding to the vi-frequency point and *n* is the total number of frequency bins considered. The assumption is that the mean value in this case reflects the expected lower boundary of the RFI density in a particular spectral slice. Extra statistics were required since, power levels, even in stationary situations, do vary over time and those variations cannot be captured by describing them with a single averaged number.

The standard deviation (σ) was calculated to assess the spread of RFI values considering the mean by using the formula below.

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(xi-\mu)^2}$$

The described approach aids in power level variability and detection of frequencies with interference that has inconsistent amplitude or non-stationary behaviour. These signal processing techniques are well known in wireless communication and environmental electromagnetic field research for evaluating a signal's quality and trustworthiness. To compare a number of sites with different baseline power levels and normalized metrics, the coefficient of variation (*CV*) was calculated, based on the following formula.

$$CV = \left(\frac{\sigma}{\mu}\right) \times 100$$

The *CV* describes the standard deviation of a particular dataset relative to its mean value. In this case, a lower *CV* is interpreted as a more stable and spectrally quiet site with steady baseline power, while a higher *CV* indicates sporadic contiguous RFI power levels. This attribute makes *CV* particularly crucial for site selection because homogeneous signal behaviour is essential in radio-astronomical observations.

The skewness (γ) coefficient was computed to assess the asymmetry of spectral power distribution. Skewness quantifies the degree to which power distribution is centred on its mean value. Positive skewness indicates that stronger, though infrequent, RFI events are disproportionately elevating the average power level. Conversely, near-zero or negative skewness is often a sign of balanced and low-level interference, which is ideal for high-accuracy measurements in radio astronomy. Thus, skewness serves as an important indicator for locating areas prone to sporadic contamination, regardless of how the average RFI levels might seem to suggest.

In addition, the kurtosis (κ) statistic was employed to describe the "peakedness" or "tailedness" behaviour of the spectral power distribution:

$$\kappa = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{xi - \mu}{\sigma}\right)^4$$

In general, extreme outliers, such as sharp peaks in radio frequency interference (RFI) that are intermittent in nature but have a huge effect on an observation's quality, are heavily skewed using sharpness. RFI spikes are infrequent and intermittent in nature and Kurtosis (κ) is extremely sensitive to these outlier peak values. High values of (κ) indicate infrequent RFI spikes. Such RFIs severely limit radio astronomy since they can easily drown out faint astronomical signals and overload their receivers. Therefore, (κ) becomes an important measurement for assessing low-quality spectral contamination, which means, or standard deviation usually fail to indicate [19-23].

Combining these parameters yields an all-inclusive assessment of each test site's spectral environment. It enables more precise judgements related to the estimation of frequency and the mitigation requirements for radio astronomical activities at PAB by quantifying central tendency, variability, asymmetry, and peak behaviour.

3. RESULTS AND DISCUSSION

This section discusses the findings based on the RFI analyses performed at the five chosen locations within PAB, concentrating on the L band (1.3-1.5 GHz), which is associated with neutral hydrogen (HI) research. This study also included descriptive statistics, hotspot detection from a level of -80 dBm, terrain shielding evaluation and an overall suitability ranking of the sites. Graphical visualization along with statistical measures such as mean, standard deviation, skewness, and kurtosis were utilized to evaluate the consistency and quality of each site's RFI environment. The results will help improve the operational and infrastructural planning for radio astronomy at PAB.

3.1 Scientific Use and Appropriateness of the L-band for Observing the Hydrogen Line

The part of the spectrum around 1400–1427 MHz is crucial in radio astronomy because it contains the 21-centimeter spectral line of neutral hydrogen (HI), which is located at 1420.4057 MHz. This HI line is critical for understanding the interstellar medium, evolution of galaxies, as well as large-scale structures in the Universe. HI line observations enable the tracing of baryonic matter, examination of galactic rotation curves and estimation of dark matter in spiral galaxies, which facilitate the study of dark matter. The line is also crucial for redshift surveys, studying the evolution of galaxies and mapping the nearby universe's cosmic web.

As the HI signal is often like microjanskys and particularly susceptible to RFI from man-made sources, such as communication towers, radars and satellites. Consequently, HI emissions from the hydrogen lines in the L-band require the deepest possible radio silence from external contaminants. The ITU (Radiocommunication), defined in ITU-R RA.769-2, sets the boundaries for radio astronomy, and stresses the need to protect the 1400–1427 MHz band from all non-science signals. Adhering to these limits ensures faint emissions of hydrogen that cannot be drowned by emissions from Earth or satellites.

Many radio observatories focus on hydrogen line research in the L-band range. SKA-Mid is planned to operate between 0.95–1.76 GHz, which is where the HI line is situated, and perform surveys of neutral hydrogen throughout the cosmic ages. SKA's sensitivity is expected to enable detection of HI in hundreds of millions of galaxies and this will transform the understanding of galaxy formation and gas accretion history [15]. MeerKAT, already operating in the 900-1670 MHz range, has launched several major HI programs, including MHONGOOSE, which studies the structure and kinematics of neutral hydrogen in nearby galaxies at high spatial resolution. Besides that, ASKAP (Australian SKA Pathfinder), working in the 700-1800 MHz range, is conducting WALLABY survey aimed at mapping HI in more than 500000 galaxies in the local universe.

As for Southeast Asia, the opening of new L-band capable observatories requires specific marking of RFI conditions. The Pusat Astronomi Borneo (PAB) is an example of an astronomical institute that is in a sub-rural tourism location and an intrinsically shielded area of Sarawak, Malaysia. Furthermore, the power levels (–80 dBm) measured across the hydrogen line window are highly stable, which indicates that hydrogen observations are possible, and it falls well within the ITU protection threshold. The site's geographic muteness together with low infrastructure and high ground vegetation shielding renders it mutes from radio interference and thus, ideal for hyper-accurate 21-cm line hydrogen observations. Given the surge in requirement for clean L-band observatories around the world to support HI surveys, PAB can play a vital role in international and regional research projects on 21cm cosmology and galactic evolution.

3.2 RFI Spectral Analysis Across Observation Sites

The field of radio astronomy requires identifying faint signals emanating from space, as they often lie in an overwhelming sea of human interference. One of the most scientifically important spectral windows is the L-band (1300–1500 MHz), particularly the hydrogen line at 1420.4057 MHz. Nevertheless, the efficacy of such observations is highly dependent on the radio wave quietness of the region. As Malaysia works to enhance its radio astronomy capability, the identification of low-RFI zones represents a critical national need. This study undertook a spectral analysis of the RFI band (within the L-band) involving five observation sites in Pusat Astronomi Borneo (PAB), namely Kuala_Sg, Hut_Bulatan, Bulatan_Off, Parit_Kuala and Tengah_PDG. The suitability of each site was measured against the practical RFI threshold of –80 dBm using *in situ* measurements and descriptive analysis based on ITU-R RA.769 norms.

Upon inspecting the entire 0–4 GHz range, as shown in the figure, all five sites showed common interference peaks at approximately 0.9 GHz, 1.8 GHz, and 2.4 GHz, which correspond to GSM, LTE, and Wi-Fi services, respectively. The peaks were most pronounced at Kuala_Sg, Bulatan_Off and Parit_Kuala, suggesting that these locations are likely within the propagation zones of some local transmitters or urban infrastructure. Observations above these bands, particularly beyond 2.7 GHz, indicate that most sites maintained spectral levels of around –80 to –85 dBm, which suggests moderate to good potential for high-frequency radio observations.

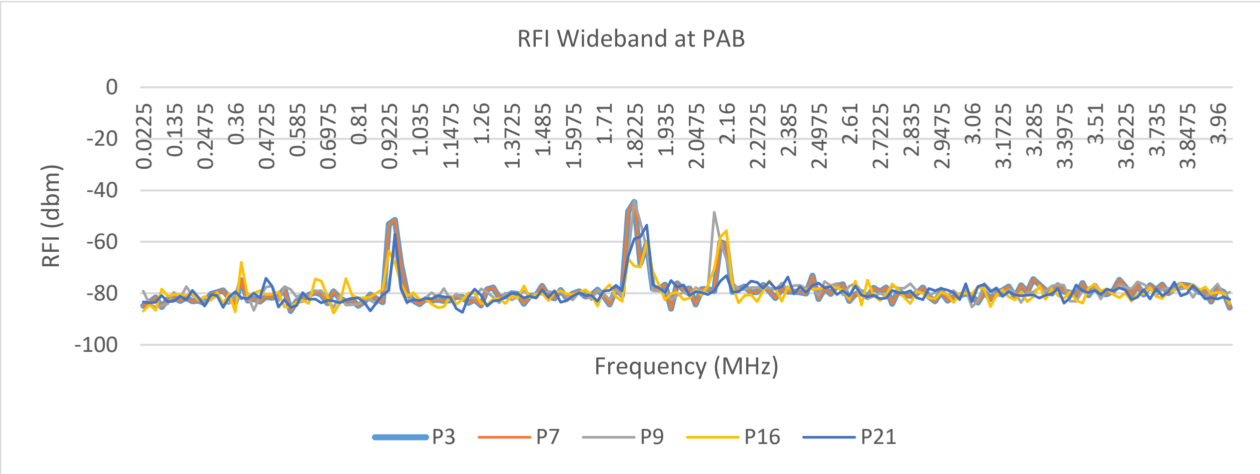

Fig. 2. Wideband RFI Spectrum (0–4 GHz) at PAB Observation Sites.

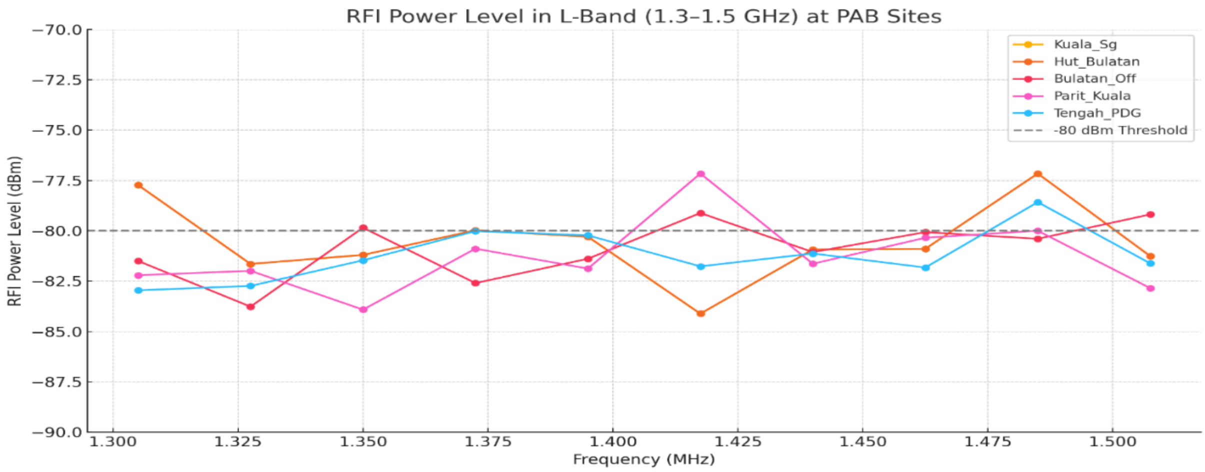

Fig. 3. RFI Power Distribution in the L-Band (1.3–1.5 GHz) at PAB Sites.

Within the L-band, most sites exhibited RFI power levels below the threshold; however, notable exceptions were found. Kuala_Sg and Hut_Bulatan recorded peak values of –77.16 dBm at 1.485 GHz, clearly exceeding the RFI protection limit. Similarly, Parit_Kuala showed a strong RFI peak at 1.4175 GHz, which also had an equivalent level. These findings indicate locational interference effects, due to nearby LTE or radar emissions. On the contrary, Bulatan_Off and Tengah_PDG presented more stable RFI interference with average levels above -80 dBm and low variability, suggesting a quieter electromagnetically polluted environment. Remarkably, none of the observation points recorded any harmful interference within the 1400 – 1427 MHz protected boundary, thus preserving the capability to observe neutral hydrogen (HI) emissions.

3.2 Descriptive Statistical Analysis of L-Band Data. Empirical measurements, such as mean, standard deviation, skewness, and kurtosis, were used to assess five selected observation points, namely Kuala_Sg, Hut_Bulatan, Bulatan_Off, Parit_Kuala and Tengah_PDG. These measurements intended to define the electromagnetic environment around PAB for L-band radio astronomy, especially for a range of 1.305 to 1.5075 MHz where the 21cm hydrogen line is detected. These RFI were created using the order statistics that summarize the average level of RFI and track its shape and power distribution, while providing useful information for assessing the reliability of the site and risks of contamination that can skew sensitive measurements.

The mean RFI levels signify the measurement values of background noise and its concentration as a metric in decibel-milliwatts (dBm). Locations exhibiting greater negative means are preferred as they signify lower average inter-reference RFI power. Tengah_PDG recorded the lowest mean power (–81.235 dBm), followed by Parit_Kuala (–81.29 dBm), which indicates radio-quiet baselines. Bulatan_Off showed a slightly elevated mean of –80.897 dBm, while Kuala_Sg and Hut_Bulatan registered a mean value of –80.522 dBm. Although the difference appears minuscule, even a 0.5–1 dBm increase in baseline RFI can severely diminish sensitivity to faint signals during spectral line measurements, like redshifted HI.

Table 2. Statistical RFI Power Levels Across L-Band Frequencies at Selected Observation Points

Descriptive Statistics	Kuala_Sg	Hut_Bulatan	Bulatan_Off	Parit_Kuala	Tengah_PDG
Mean	-80.522	-80.522	-80.897	-81.29	-81.235
Std. Deviation	1.969	1.969	1.488	1.854	1.318
Skewness	0.203	0.203	-0.706	1.091	0.76
Kurtosis	0.841	0.841	-0.002	2.12	0.511
Kurtosis Indicator	Mesokurtic	Mesokurtic	Platykurtic	Leptokurtic	Platykurtic
Minimum	-84.116	-84.116	-83.774	-83.922	-82.957
Maximum	-77.162	-77.162	-79.124	-77.16	-78.581

Standard deviation (σ) is a statistical method depicting the scattering of data points in different RFI power measurements and signifies the precision and steadiness of the signal. Predictability of the floor estimated noise improves with lower fluctuation; hence, lower standard deviation is more favourable. Again, Tengah_PDG performed best with the lowest $\sigma = 1.318$ dBm, and Bulatan_Off was not far behind with $\sigma = 1.488$ dBm. In contrast, Kuala_Sg and Hut_Bulatan with higher RFI spreads ($\sigma = 1.969$ dBm) are estimated to provide a more turbulent spectrum, which could be dominated by a mix of intermittent transmissions from human constructed devices or coupling effects caused by the weather. The observed minimum and maximum RFI values are evidence of the range within which the signal strength undergoes variation. Kuala_Sg and Hut_Bultan had RFI maxima of –77.162 dBm, while their minima was –84.116 dBm, indicating a significant dynamic range with sporadic RFI bursts. Among all the sites, Bulatan_Off demonstrated the highest peak stability, with a range of –83.774 dBm (min) to –79.124 dBm (max), thus, supporting the symmetry between the site's favourable distribution and lack of dominant transients. Even though Tengah_PDG's peak value of –78.581 dBm was moderate, its minimum of –82.957 dBm reinforced the site's overall suitability. As a third moment statistic, skewness quantifies the asymmetry in the power-curve profile. Observation of a positively skewed value would indicate a tail stretching towards a higher (or less negative) RFI value. This is typically associated with weak but intermittent and impulsive interference, often associated with short bursts from local communication towers or electronic apparatus. In this context, Parit_Kuala (+1.091) and Tengah_PDG (+0.760) showed strong right-skewed RFI distributions, which suggests RFI dominated by frequent transient power spikes that could alter the detection of faint spectral lines in passive radio observations. However, Bulatan_Off showed negative skewness (-0.706) thus suggesting a left skewed distribution with a larger proportion of low measurements and a few weak outliers. This is desirable in radio astronomy because it indicates few disruptive events that contaminate the median signal.

An analysis of the L-band RFI power distribution's kurtosis across the five observation sites yielded useful insight into their statistical characteristics and relative fitness for radio astronomy. In this case, kurtosis quantifies the "peakedness" of the RFI data distribution, which is tied to the presence or absence of narrowband interference, in this case, the strong one. Distribution with platykurtic characteristics (kurtosis < 1.0) was less peaked and this denotes more uniform RFI power with reduced extreme spikes or bursts, making it preferable during sensitive radio astronomy measurements. Bulatan_Off and Tengah_PDG with kurtosis values of -0.002 at 0.511, respectively, can both be considered platykurtic. These sites exhibit a stable RFI profile and are unable to exceed a fixed power level or generate power peaks. Thus, both sites are beneficial for radio astronomy, especially in cases that require long integration times and for measuring the hydrogen line where low interference is paramount.

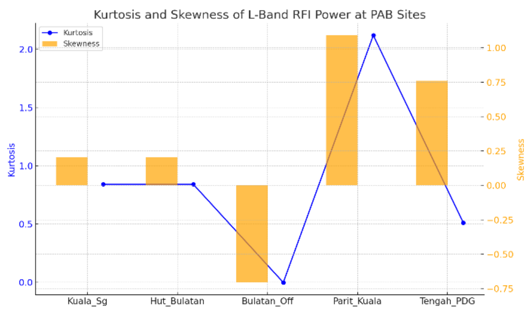

Fig. 4. Skewness and Kurtosis Analysis Across PAB Observation Sites.

As for Kuala_Sg and Hut_Bulatan, both are classified as mesokurtic sites, having a kurtosis value of 0.841. These sites have moderately normal distributions containing some RFI peaks, but not excessive amounts. Roughly resembling platykurtic environments, these areas are not as ideal as other locations but provide acceptable stability that makes them radio quiet. These sites could be better suited for radio observations with some additional shielding or filtering. In contrast, Parit_Kuala's markedly greater value of 2.120 places it in the leptokurtic category. This signifies sharp peak distributions densely clustered with heavy tails, indicative of intense and sudden surges of RFI. In turn, this demonstrates high spectral variability and strong interference sources that stridently diminish Parit_Kuala's suitability for radio astronomy, unless significant counteractive measures are employed. In summary, peripheral sites exhibit platykurtic profiles and are most promising, while others with mesokurtic or leptokurtic distributions are prioritized for further RFI control or may be deprioritized in observatory planning.

3.4 Frequency of Hotspot Detection and Thresholding

The L-band spectrum from 1.3 to 1.5075 GHz was investigated for RFI hotspots at five observation sites, namely Kuala_Sg, Hut_Bulatan, Bulatan_Off, Parit_Kuala, and Tengah_PDG. A conservative detection threshold of –80 dBm, which is considered internationally accepted practice for radio astronomy RFI limits, was used for the analysis. Any signal that hits this threshold is classified as significant interference or a hotspot since they risk sensitive observation of the hydrogen line (1420.4057 MHz).

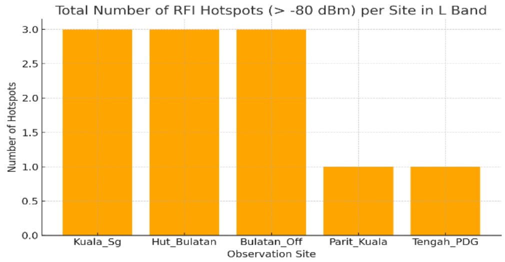

Fig. 5. Number of RFI Hotspots (> -80 dBm) per Site.

The analysis found that Hut_Bulatan, Bulatan_Off, and Kuala_Sg showed three frequency points of interference higher than –80 dBm. While there is evidence of spectral contamination, the interference remains at a moderate level. These peaks are attributed to intermittent local telecommunication or other electronic emissions. Parit_Kuala and Tengah_PDG showed better spectral conditions with lower interference, but positive peaks of only one hotspot above the detection threshold.

It is noteworthy that Parit_Kuala recorded a RFI hotspot at approximately 1.4175 MHz with a strong spike of –77.16 dBm, associated with out-of-band spurious emissions. The use of frequency-specific thresholding offers pivotal insight for determining site qualification. Sites with lower hotspot count, such as Parit_Kuala and Tengah_PDG, showed greater RFI suppression and thus, better suited for L-band radio astronomy. The identification of certain spectral contamination patterns serves some purpose for mitigation techniques, such as bandpass filtering and dynamic avoidance of pre-programmed interference periods. The hotspot distribution aligns with the gradual tactical expansion of PAB as a protected observation zone with prioritized site selection based on spectral filth.

3.5 Environmental RFI Risk Assessment and Terrain Shielding

To establish the optimal location for L-band radioastronomy at Pusat Astronomi Borneo (PAB), five different sites were evaluated based on the following RFI metrics, namely average RFI power, standard deviation of RFI, number of RFI hotspots located above -80 dBm, and natural terrain shielding around the sites. Sites with lower RFI, fewer hotspots, and better natural shielding are better suited for 1420 MHz hydrogen line observations.

Among all the sites, Tengah_PDG yielded the best results by exhibiting the lowest average RFI power, low RFI variation, and only one RFI hotspot. Most importantly, the site was well shielded by forests and terrain. Bulatan_Off was also promising as it exhibited strong signal conditions with slight variation. Parit_Kuala showed low average RFI; however, evidence of sporadic strong interference was also noted. Kuala_Sg and Hut_Bulatan had the highest concentration of hotspots, but due to increased exposure to man-made signals, these sites were rendered the least suitable without some form of intervention. In summary, the first recommendation for L-band observations is Tengah_PDG, with Bulatan_Off coming second. The other sites may require some form of shielding or filtering.

Table 3. Decision Table for Site Ranking Based on Relevance to RFI

Site	Rank	Justification
Tengah_PDG	1	Lowest mean RFI, lowest σ, high shielding, low hotspots – ideal for HI work.
Bulatan_Off	2	Stable distribution (low σ, negative skew, near-zero kurtosis), moderate exposure.
Parit_Kuala	3	Low mean RFI but high kurtosis/skewness, indicating impulsive RFI bursts.
Hut_Bulatan	4	High exposure and variance, RFI exceeds threshold frequently.
Kuala_Sg	5	Like Hut_Bulatan, with high environmental RFI vulnerability.

4. CONCLUSION

An analysis of RFI in the HI line from 1.3 to 1.5 GHz in five observation sites within Pusat Astronomi Borneo (PAB) found that Tengah_PDG was the most suitable site for radio astronomy observations. This site exhibited the lowest average RFI throughout the survey, strong natural shielding by the terrain and minimal interference variation. Bulatan_Off also demonstrated some potential, while Hut_Bulatan, Parit_Kuala and Kuala_Sg were severely affected by environmental RFI. This study demonstrates how a combination of spectral analysis with site situational awareness enables effective planning for radio quiet buffers and radio astronomy infrastructure in the country.

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